



## Measurement of the rotor wake using PIV on a scaled turbine rotor in a water flume

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*Publication date:*  
2013

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*Citation (APA):*  
Mikkelsen, R. F. (Author), Okulov, V. (Author), Meyer, K. E. (Author), Naumov, I. (Author), Karbardin, I. (Author), & Sørensen, J. N. (Author). (2013). Measurement of the rotor wake using PIV on a scaled turbine rotor in a water flume. Sound/Visual production (digital)

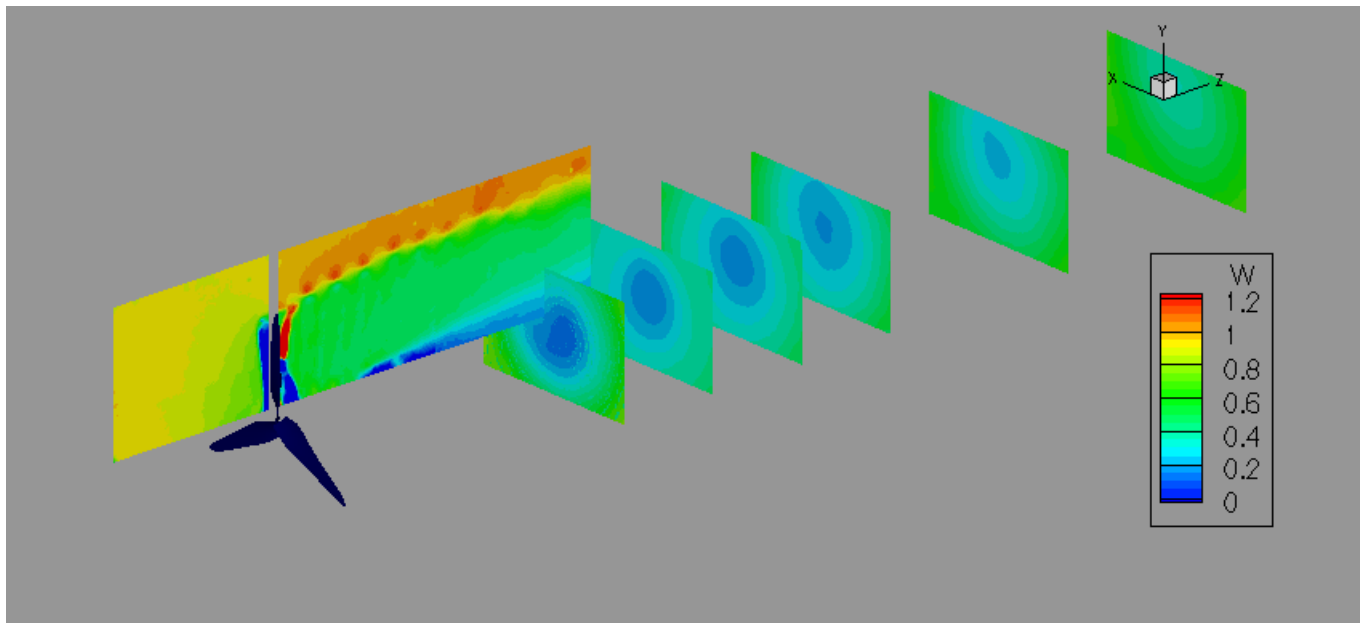
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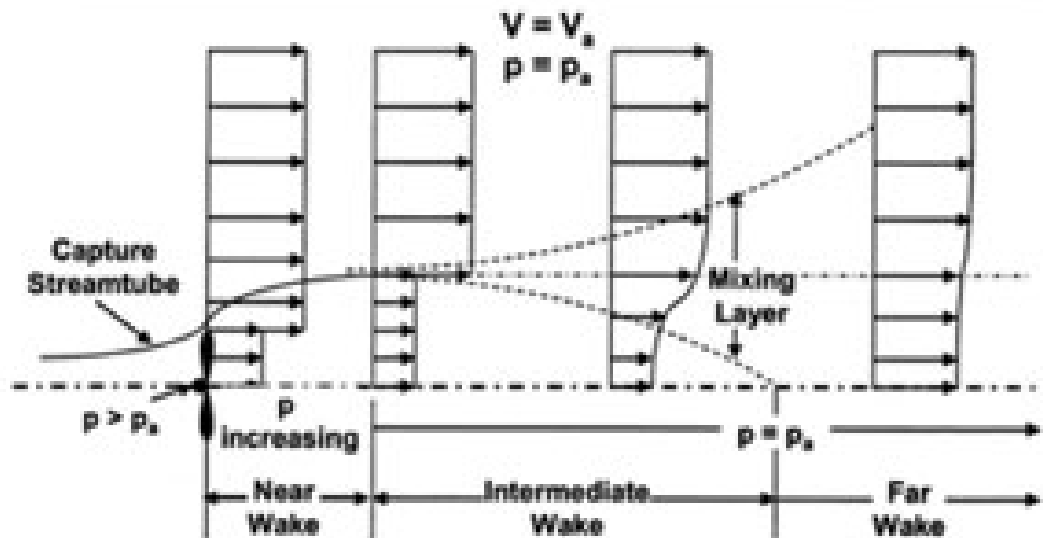
# Measurement of the rotor wake using PIV on a scaled turbine rotor in a water flume

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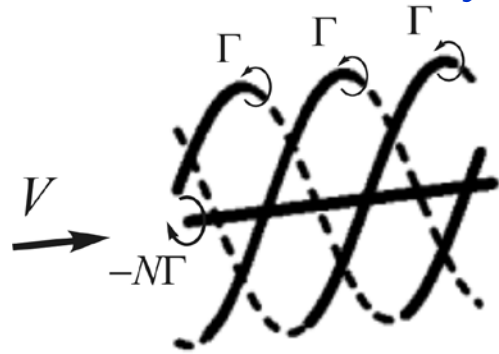
# Motivation to this study is the incomprehensible wake!



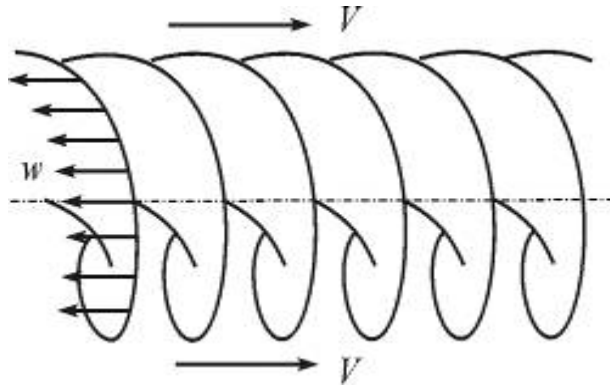
*An alternative presentation of the wake: near wake – far wake – turbulent wake*

# The next motivation is to study of the wake behind Glauert rotor

## Wake behind Joukowsky rotor - I



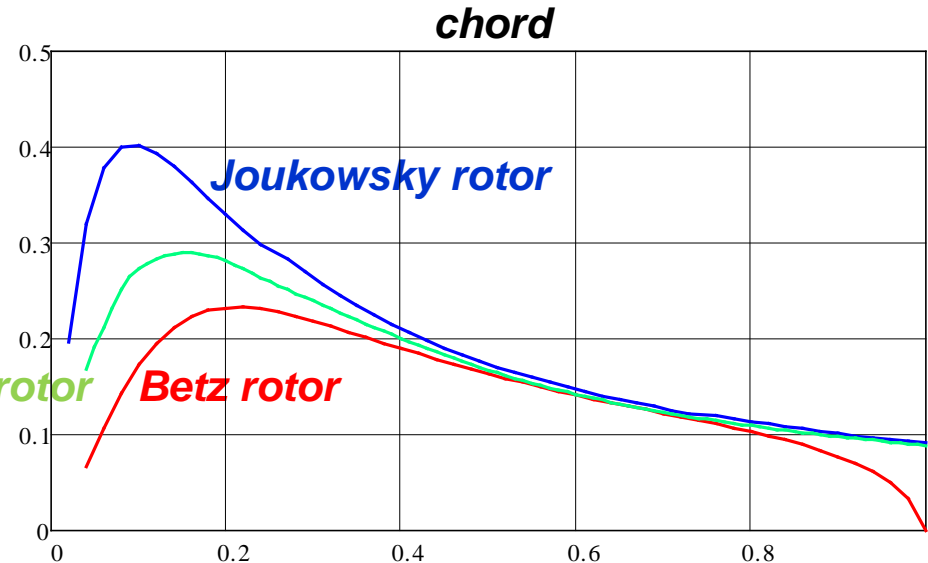
## Wake behind Betz rotor - II



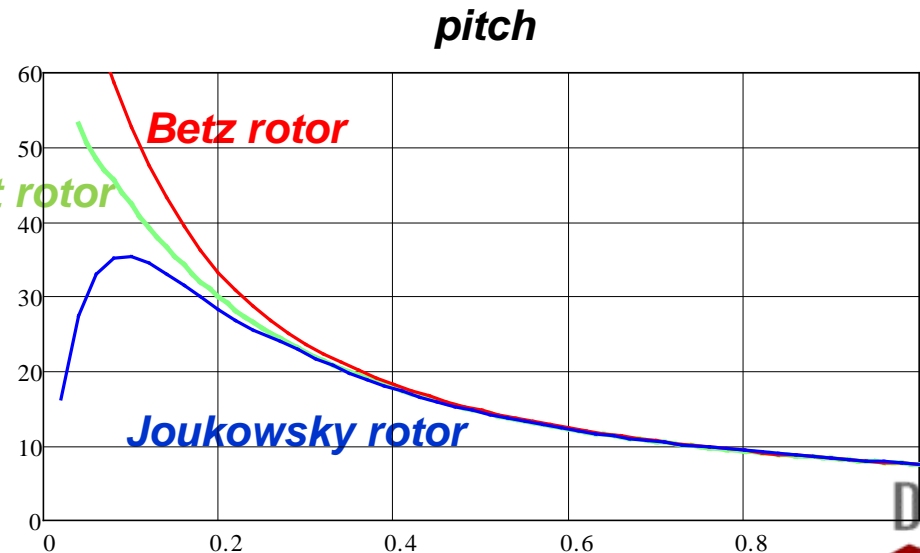
What is a wake behind Glauert rotor?



Danmarks Tekniske Universitet



Glauert rotor Betz rotor



Betz rotor

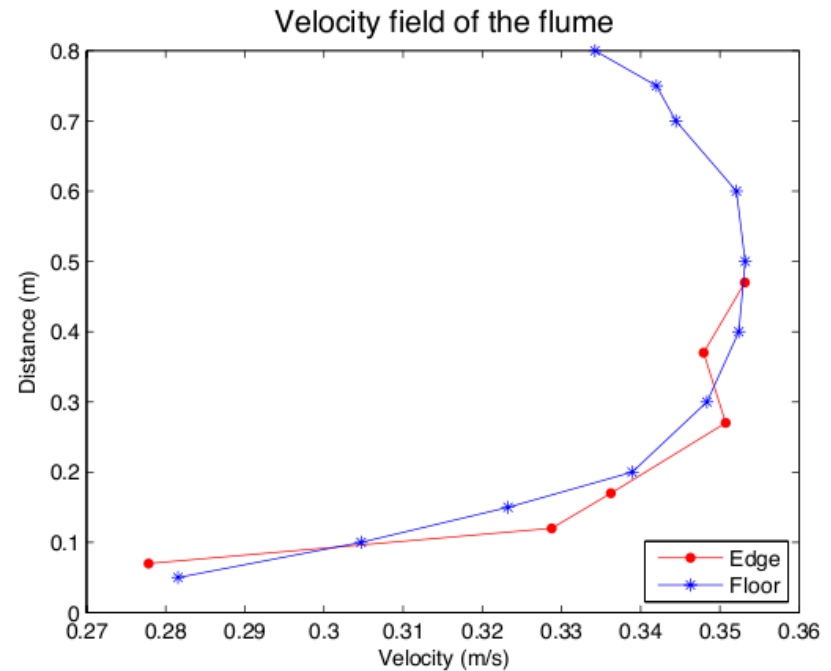
Glauert rotor

Joukowsky rotor

# Flume



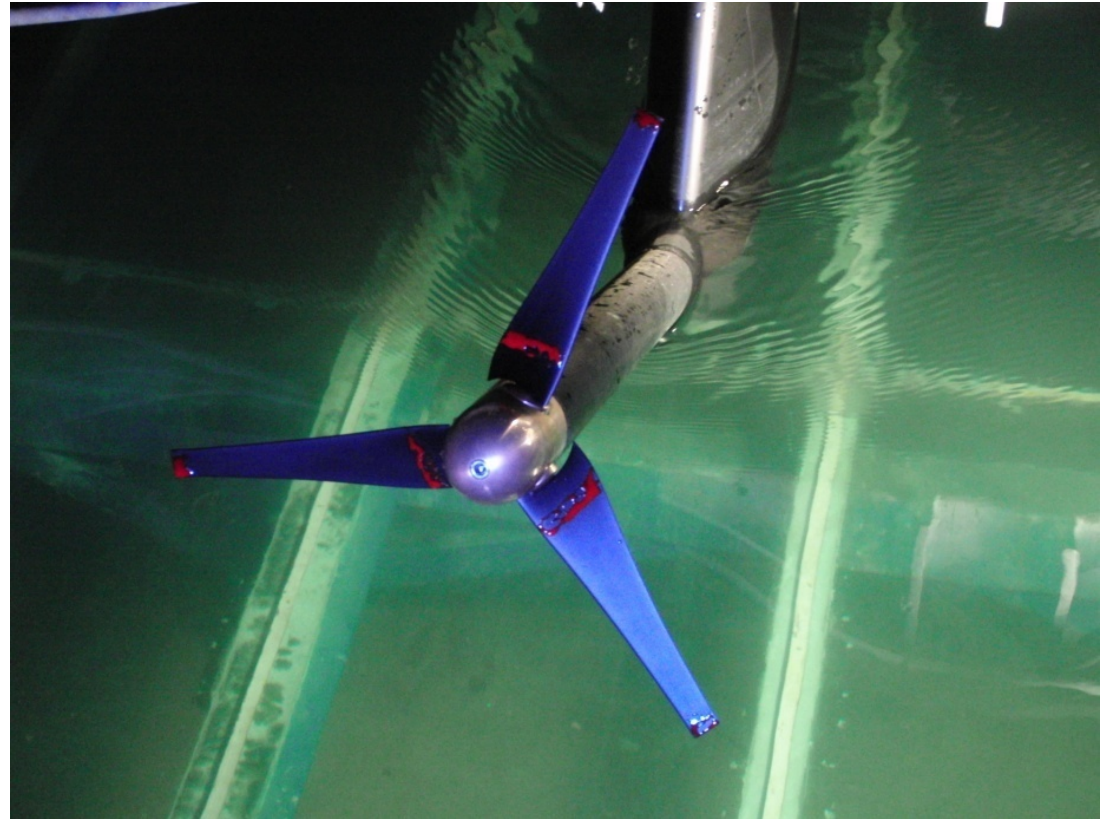
- $V_0 = 0.38$  and  $0.5$



# ROTOR

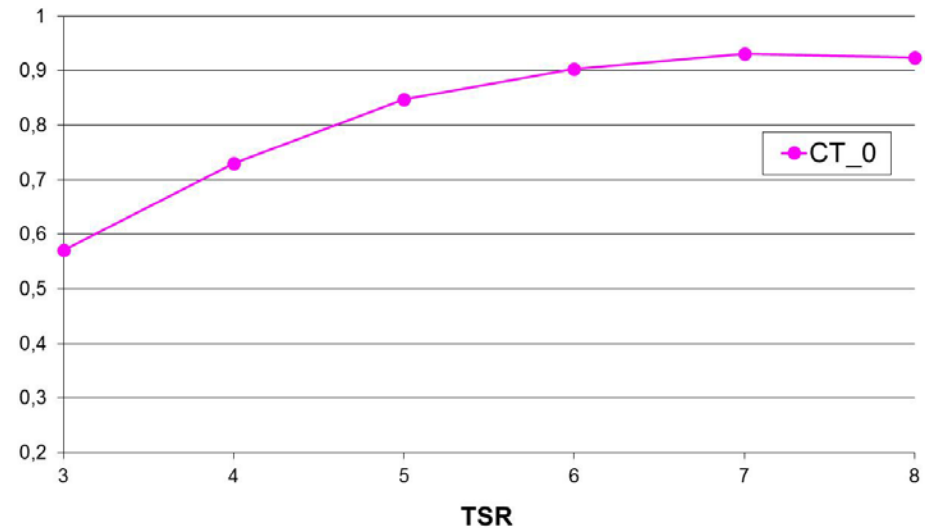
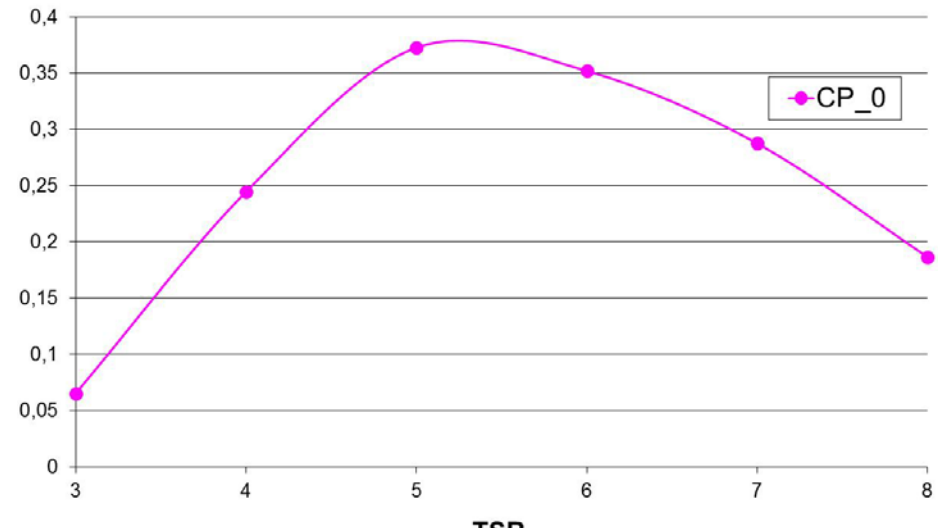
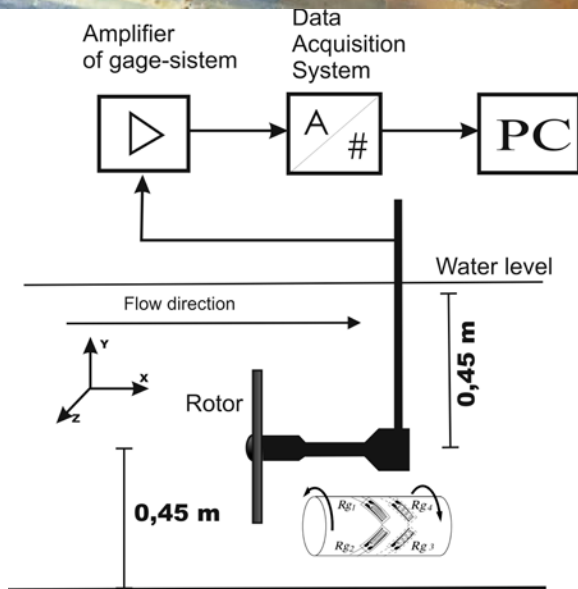
The current study is turbine by Glauert opt. for  $\lambda=5$

- $D=0.35\text{m}$
- SD7003 aerofoil
- $Re = 20\ 000$
- $V_0 = 0.38$  and  $0.5$

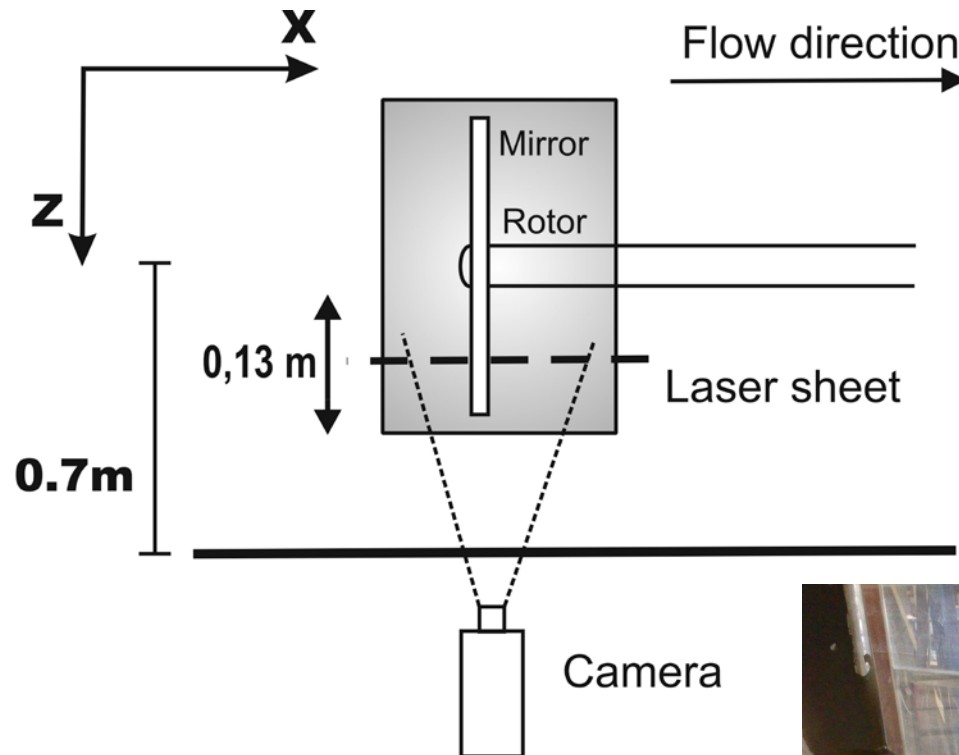




# Measurement of the power and trust



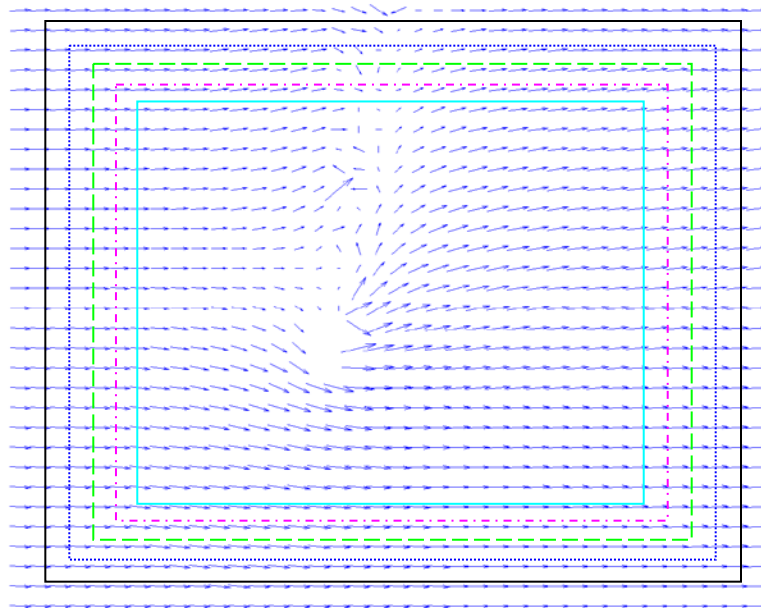
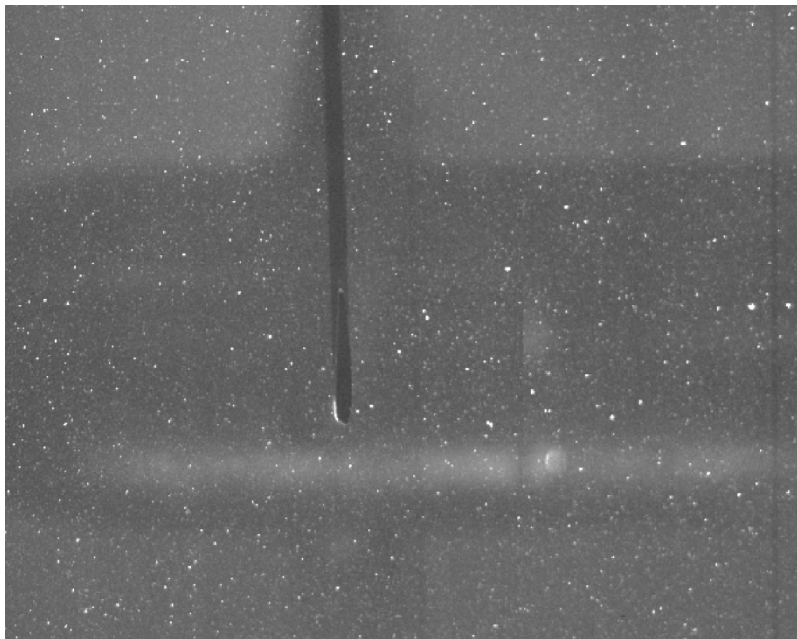
# Measurement of the blade circulation





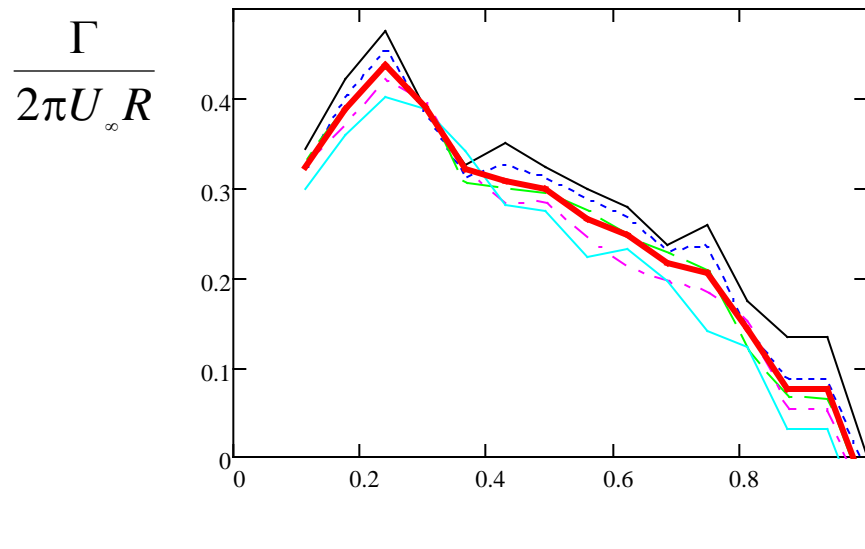
# Blade circulation

$\lambda = 3$

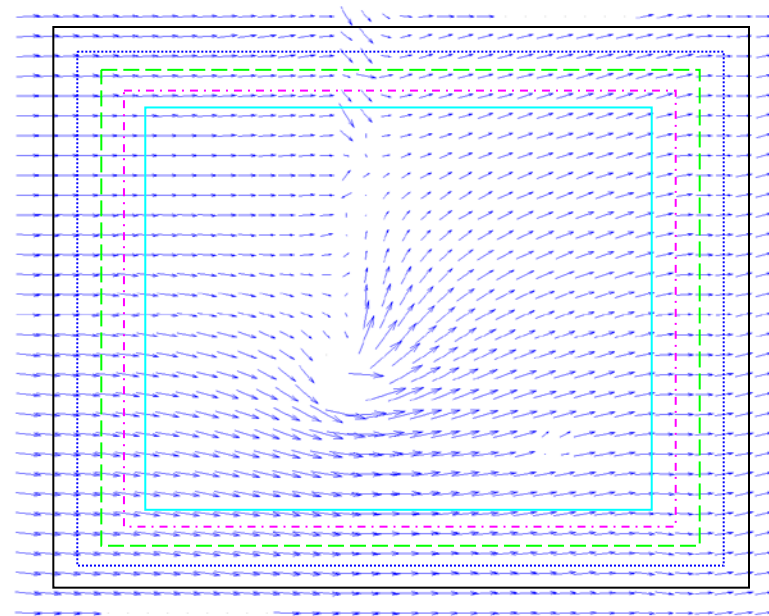


Circulation

$$\Gamma = \oint \vec{u} \cdot d\vec{l}$$



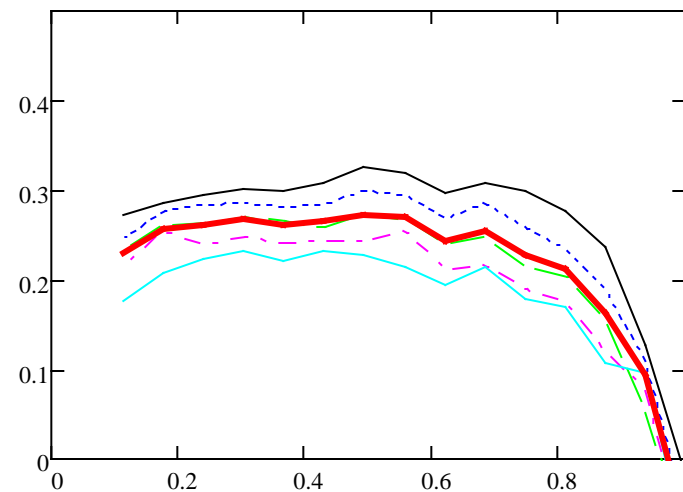
# Blade circulation $\lambda = 5$



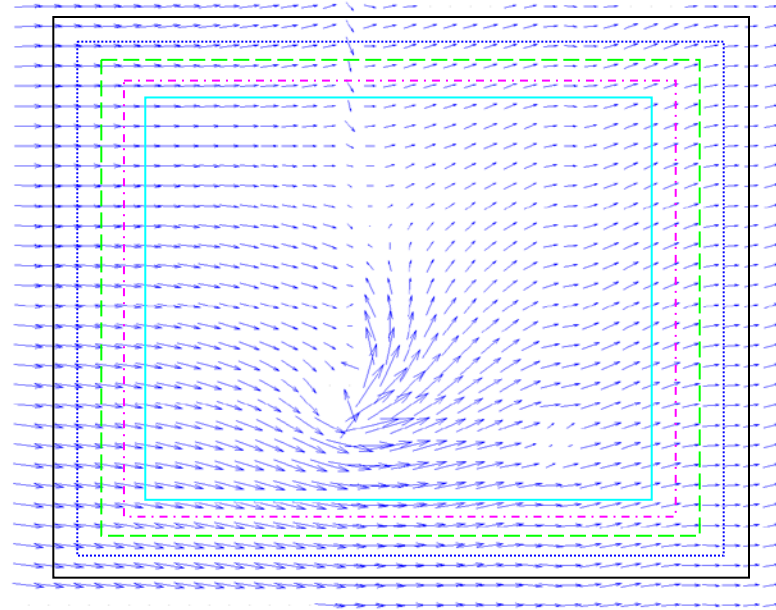
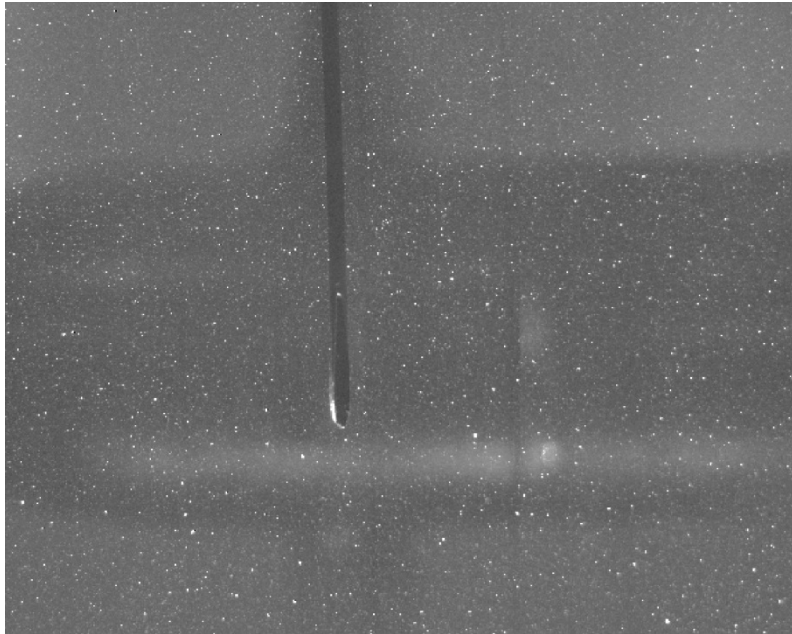
Circulation

$$\Gamma = \oint \vec{u} \cdot d\vec{l}$$

$$\frac{\Gamma}{2\pi U_{\infty} R}$$



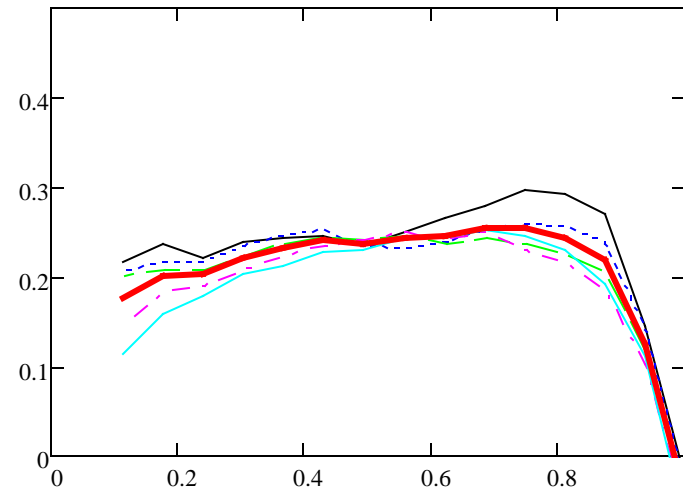
# Blade circulation $\lambda = 7$



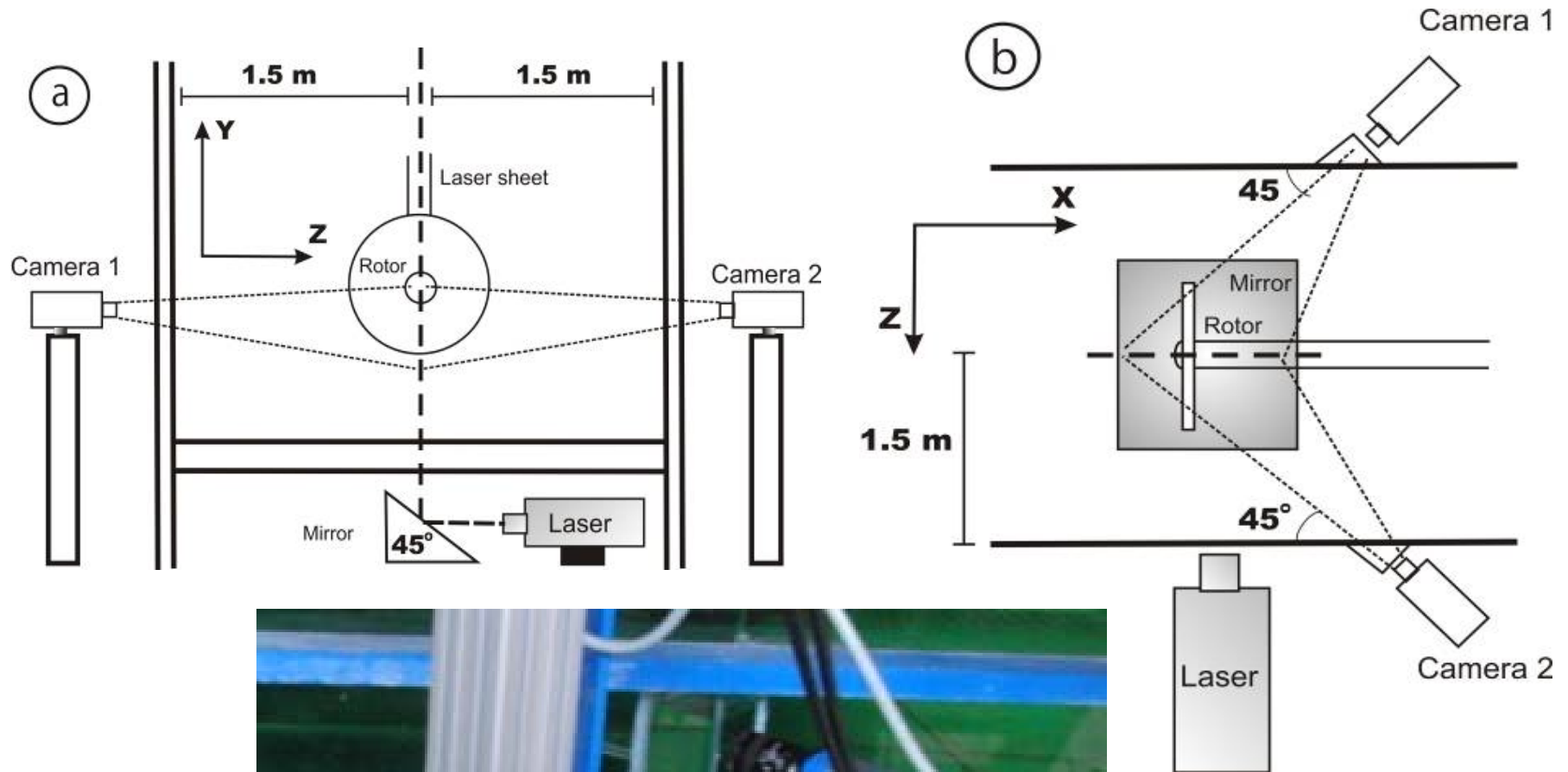
Circulation

$$\Gamma = \oint \vec{u} \cdot d\vec{l}$$

$$\frac{\Gamma}{2\pi U_{\infty} R}$$

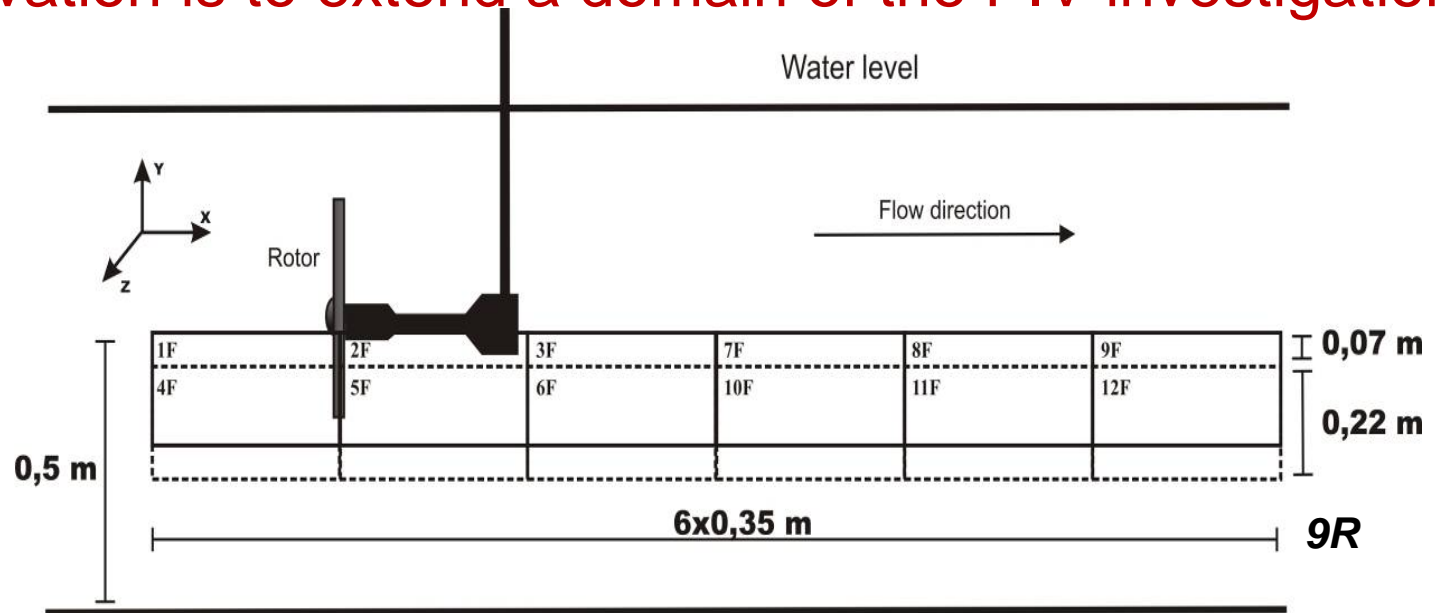


# Sketch of the setup with stereoscopic PIV

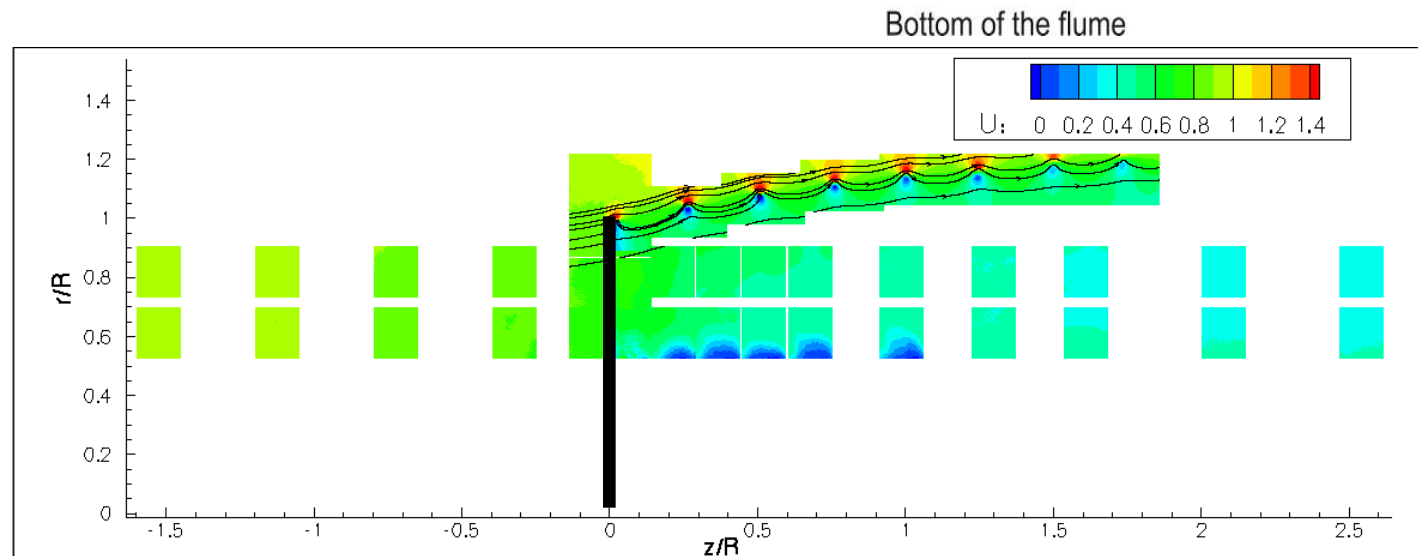


# New motivation is to extend a domain of the PIV investigation

Sketch of  
12 testing  
windows of  
the current  
experiment



Sketch of  
the windows  
in the  
“MEXICO”  
PIV-  
experiment





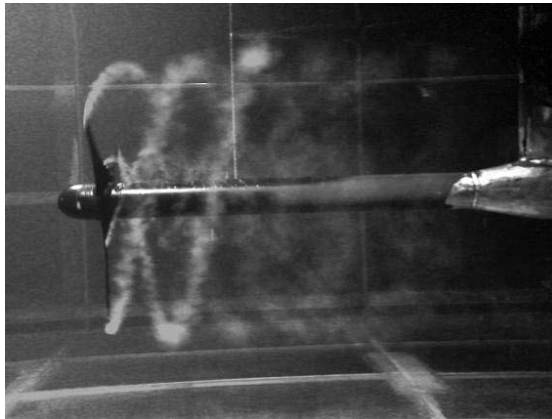
# Visualizations of WT's wake $TSR=6$



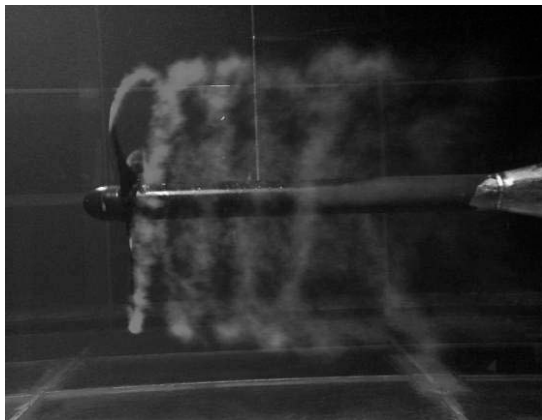


# Visualizations of WT's wake for different TSR

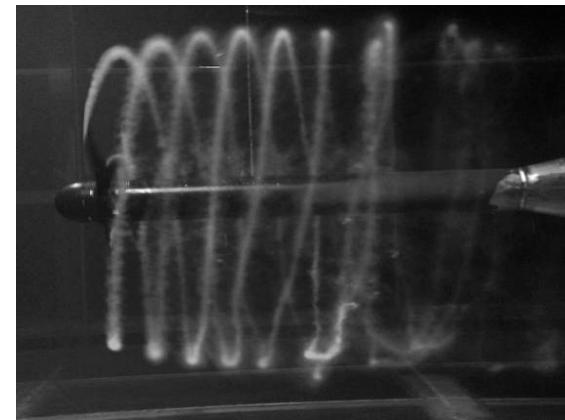
$\lambda=4$



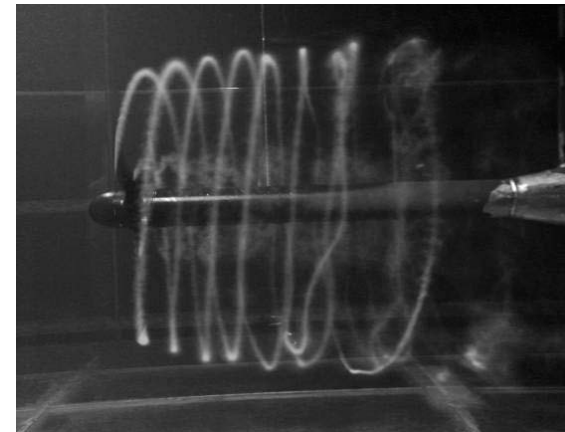
$\lambda=5$



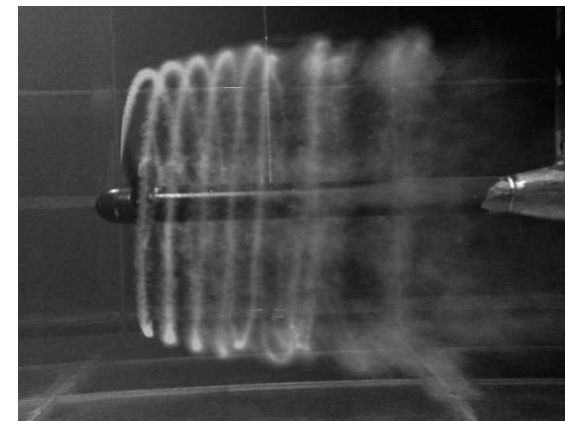
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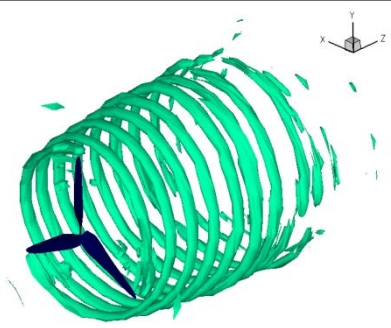
$\lambda=7$



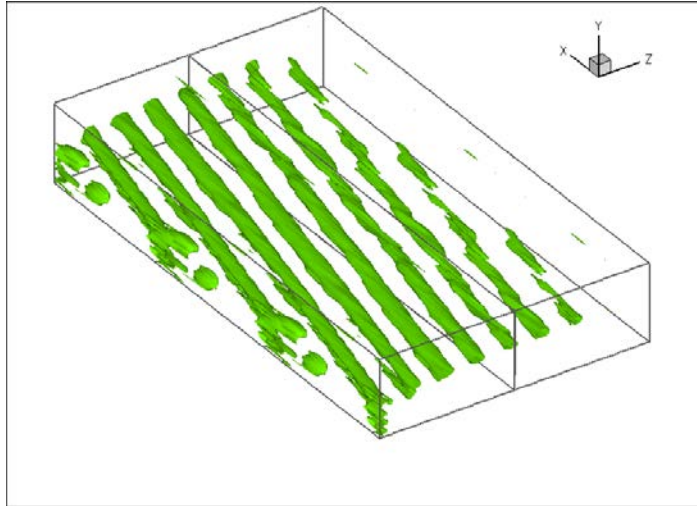
$\lambda=8$



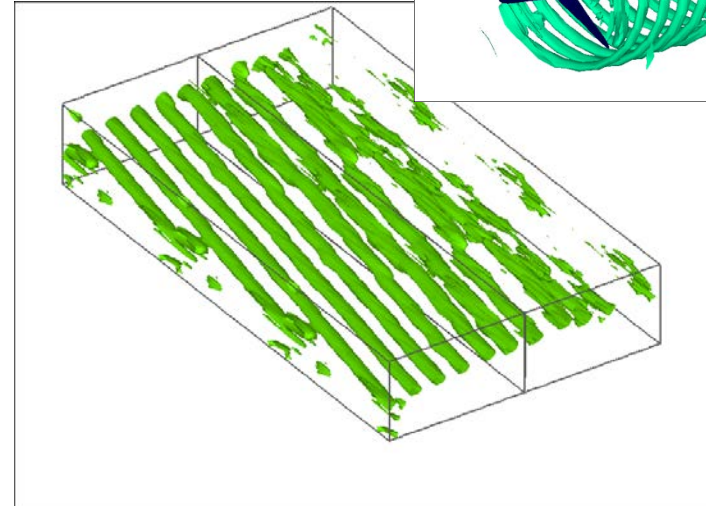
# Tip vortex structure, unfolded, 0,15,30,45,60,75,90,105 deg



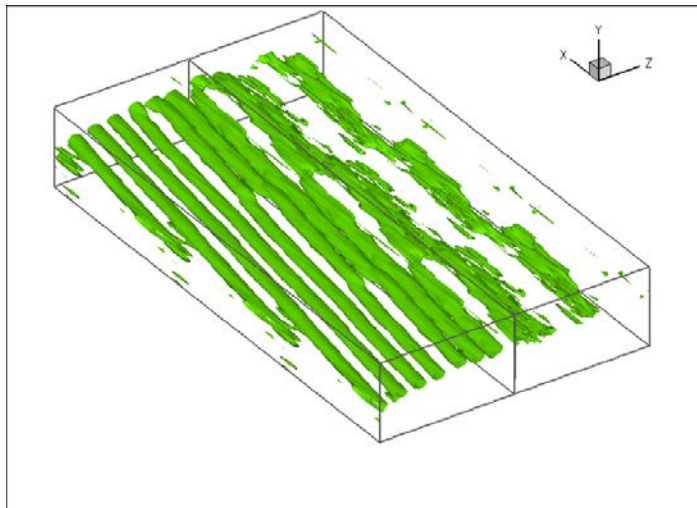
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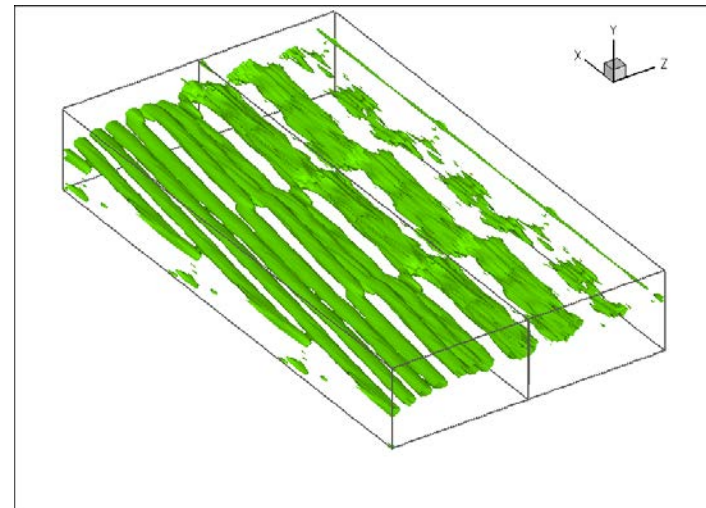
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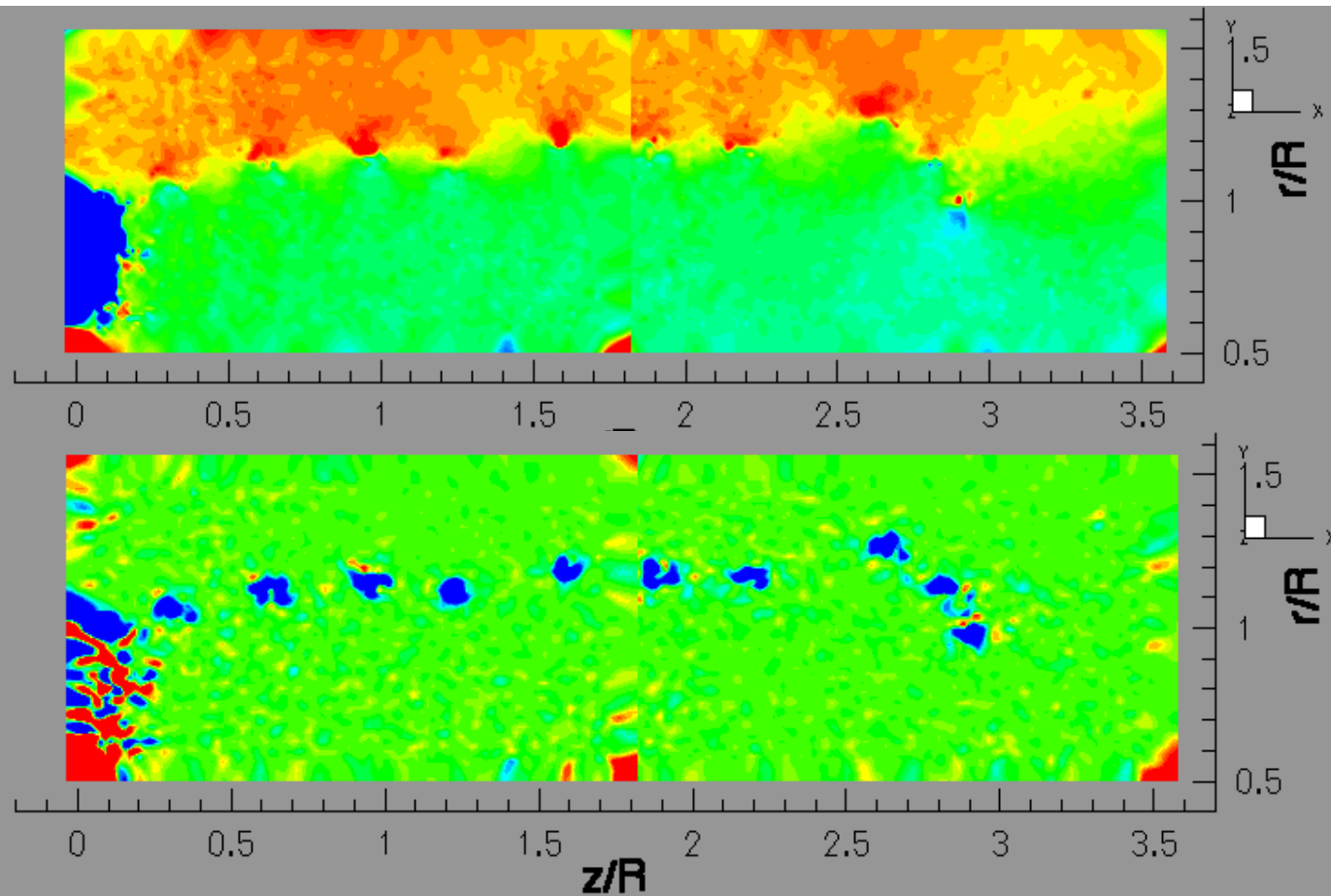
$\lambda=6$



$\lambda=7$



# Axial velocity, TSR=6, 100 images

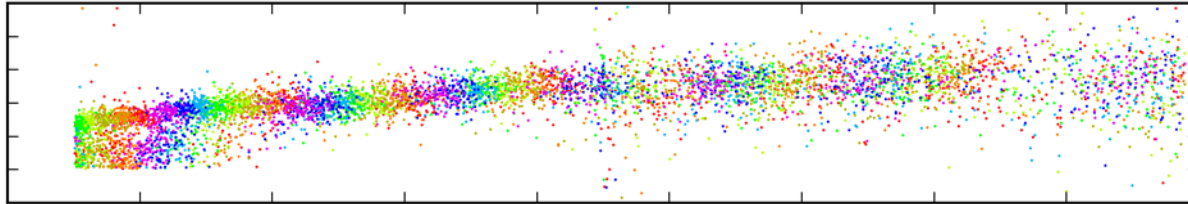


U ax.

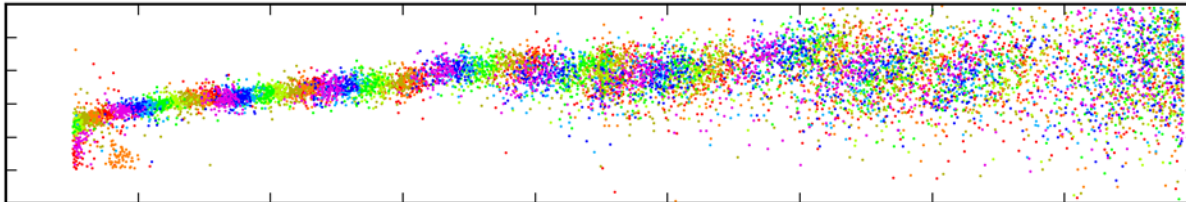
Vorticity

# Instantaneous location of vortex center 0,15, 30,45,60,75,90,105 deg

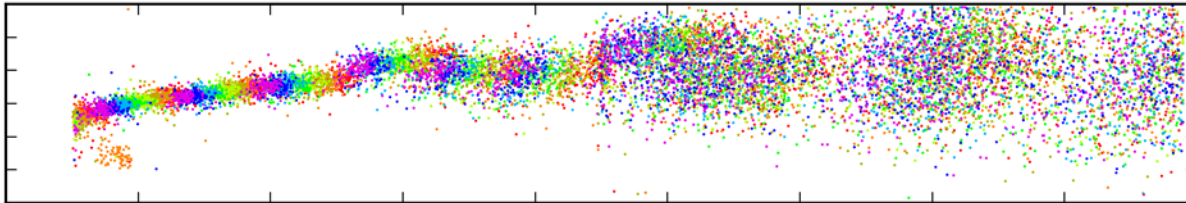
$\lambda=4$



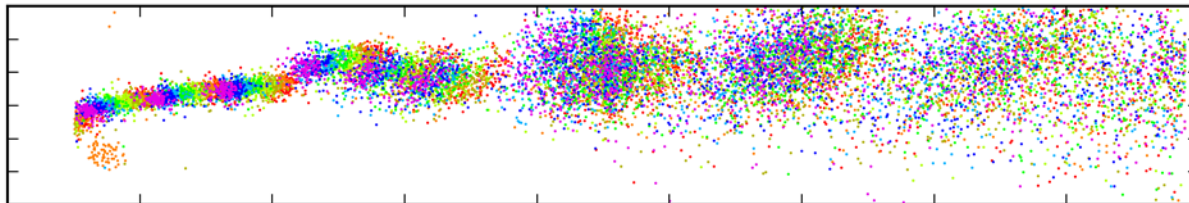
$\lambda=5$



$\lambda=6$

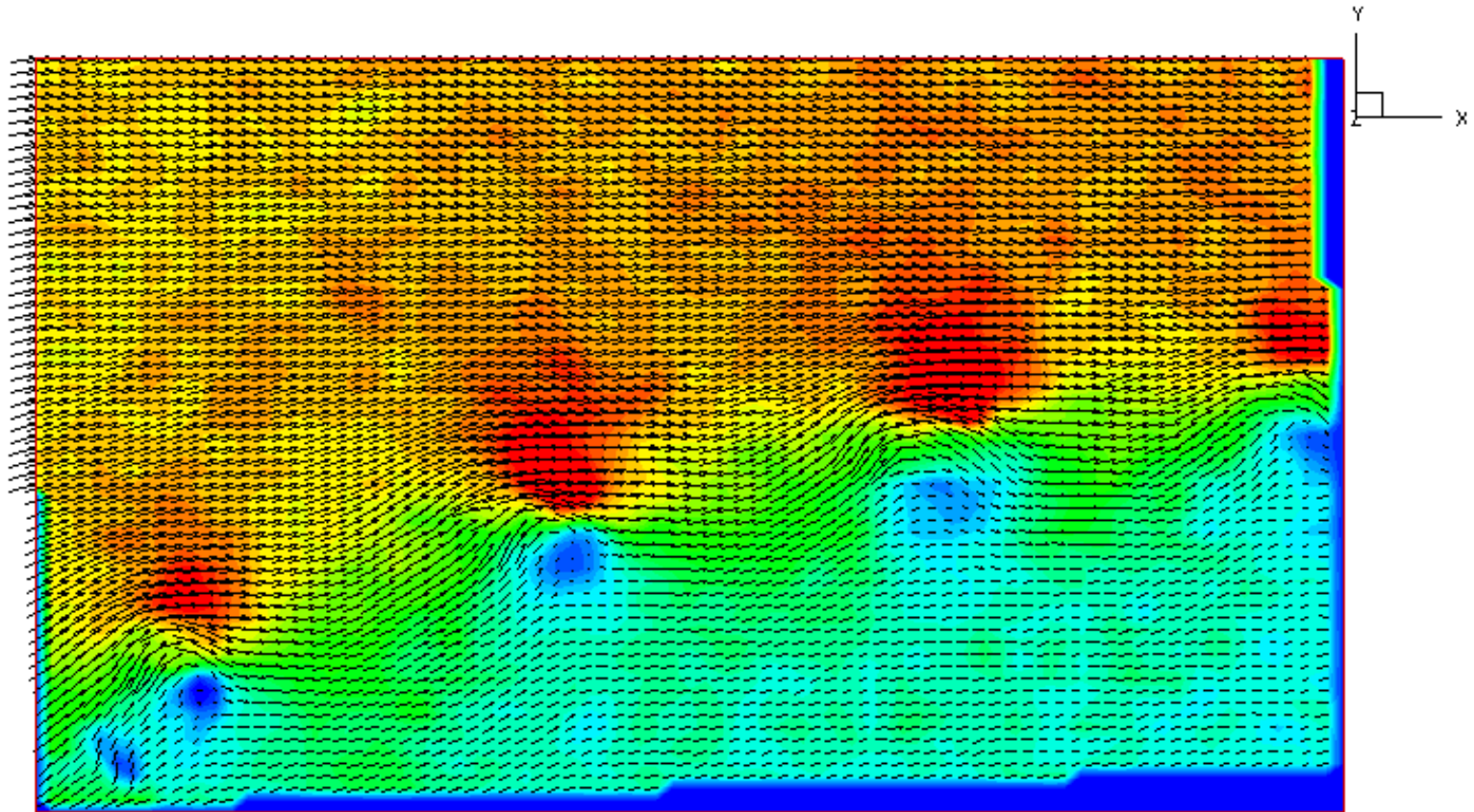


$\lambda=7$



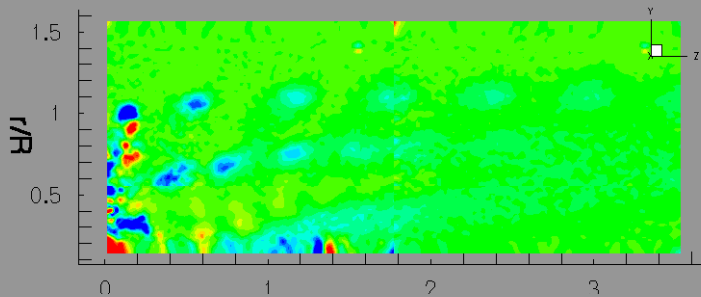


# Tip vortex and vectors, TSR=6

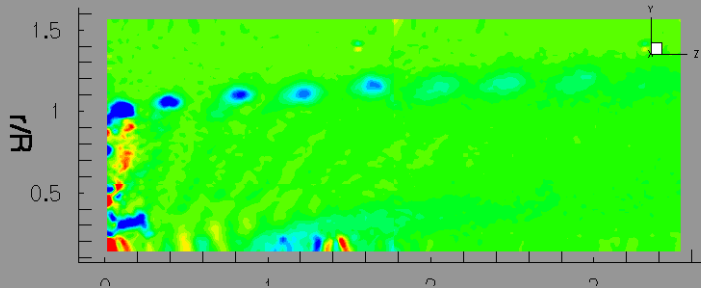


# Tip vortex – vorticity, phase averaged, TSR=3-7

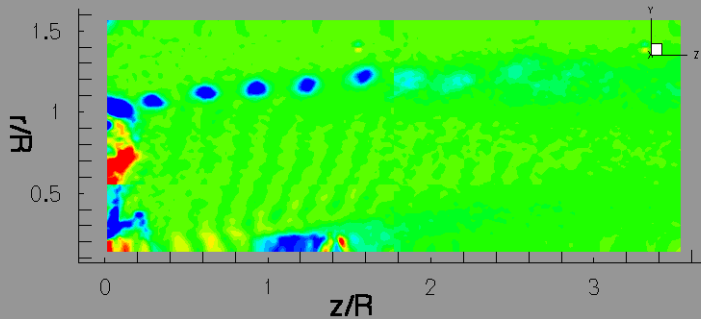
$\lambda=3$



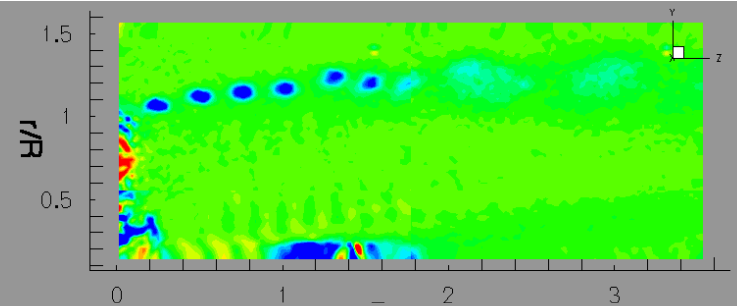
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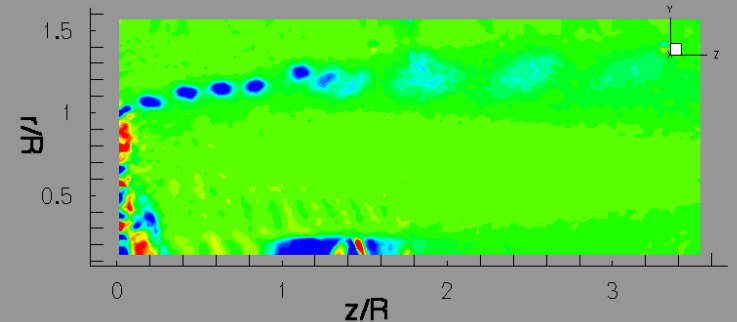
$\lambda=5$



$\lambda=6$



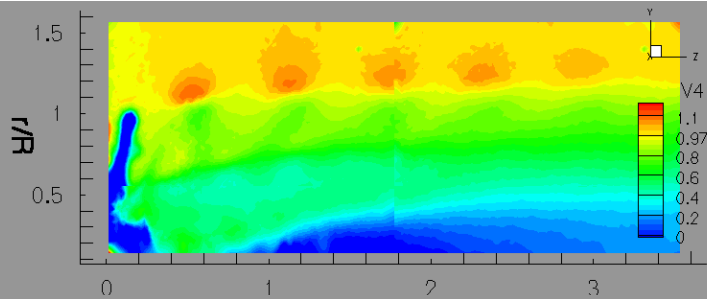
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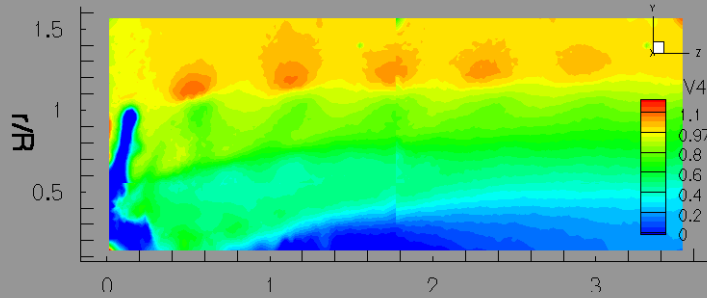


# Axial velocity, phase averaged, TSR =3-5

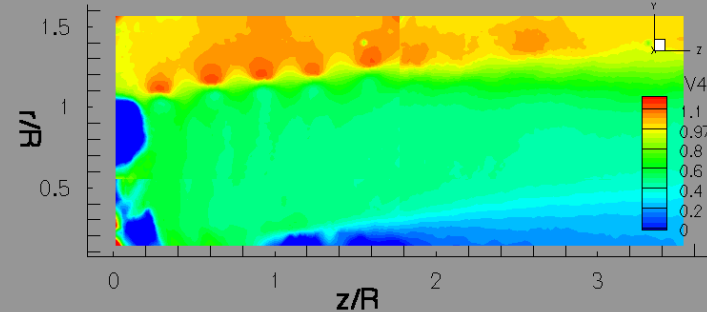
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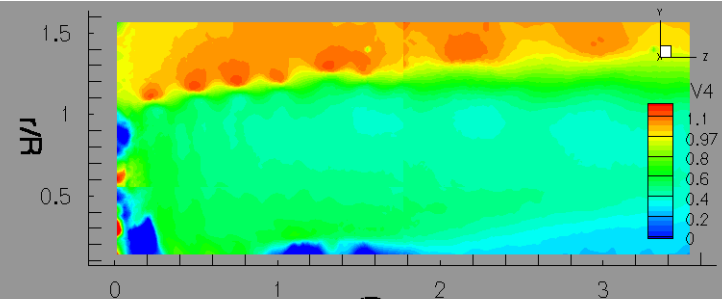
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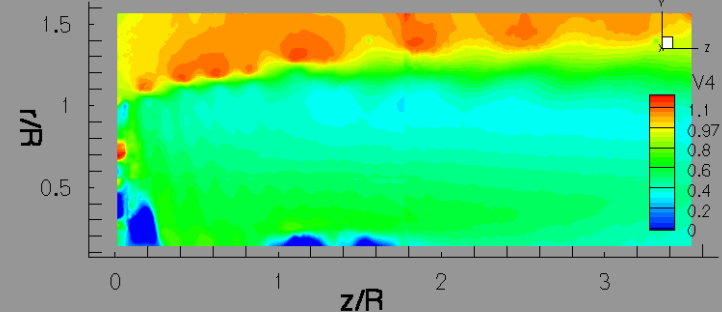
$\lambda=5$



$\lambda=6$

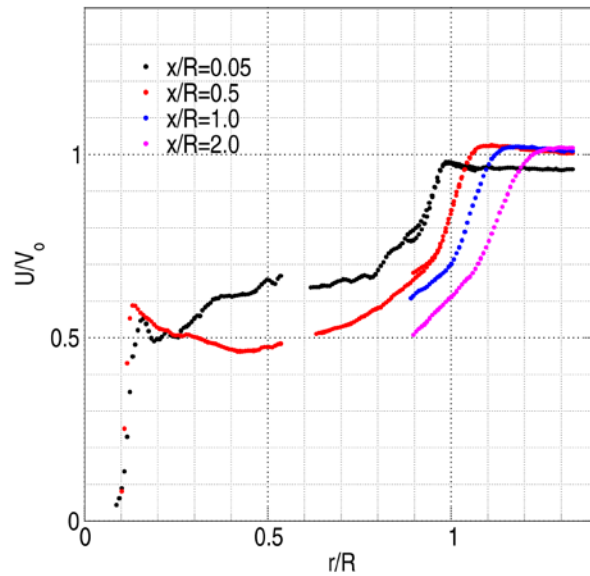


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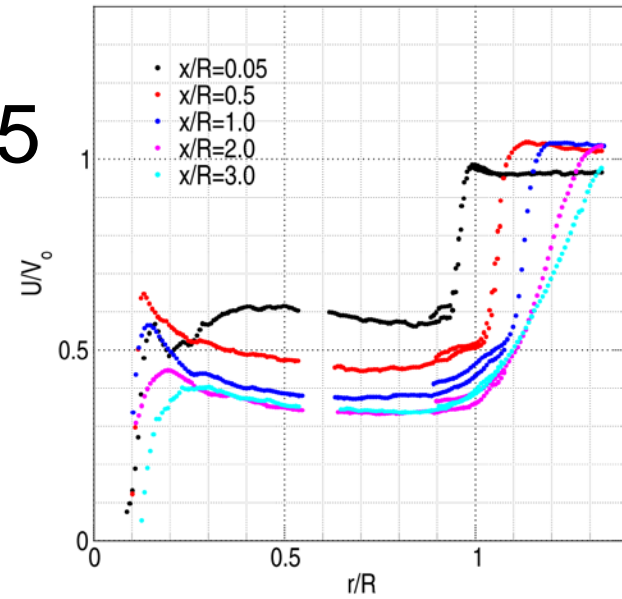


# Mean Axial Velocity U, TSR 4-7

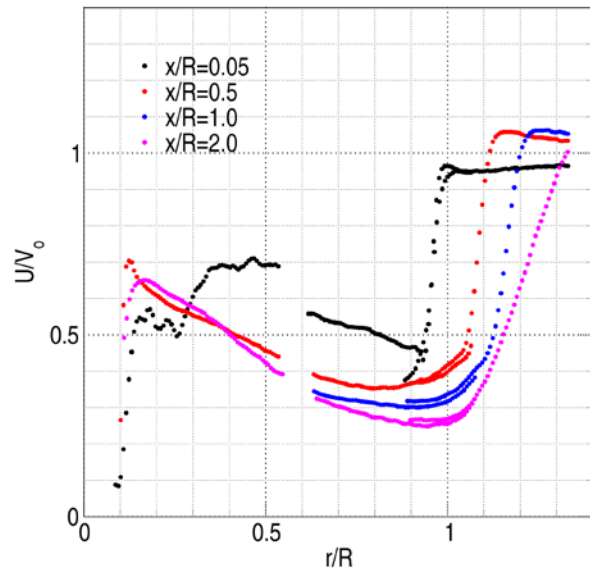
4



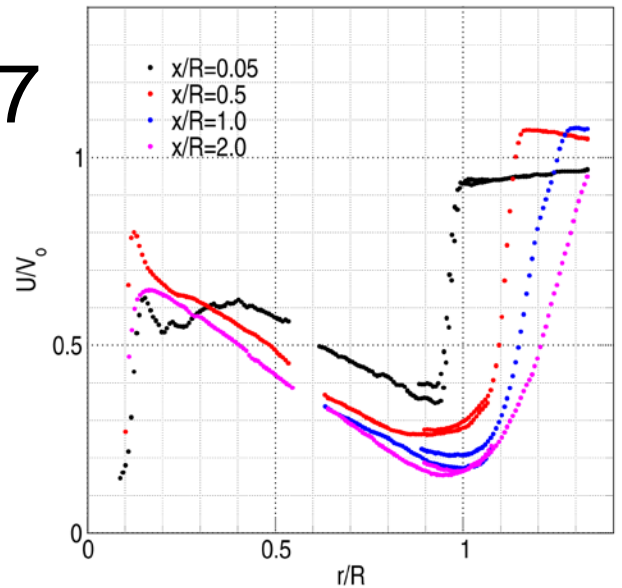
5



6

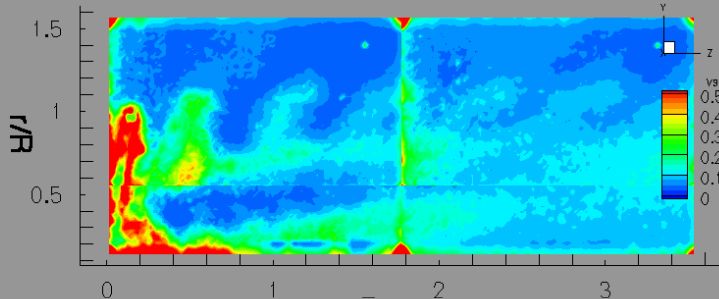


7

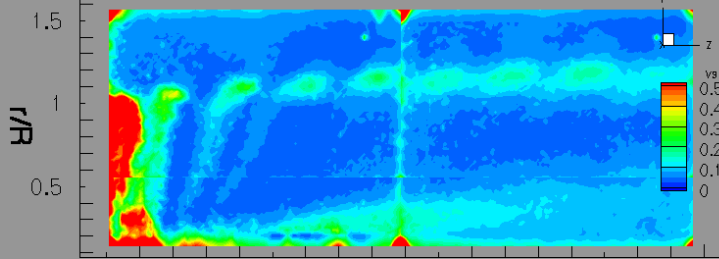


# Axial velocity, $U_{rms}$

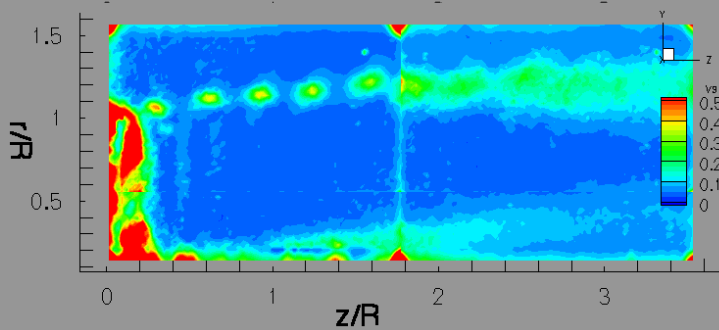
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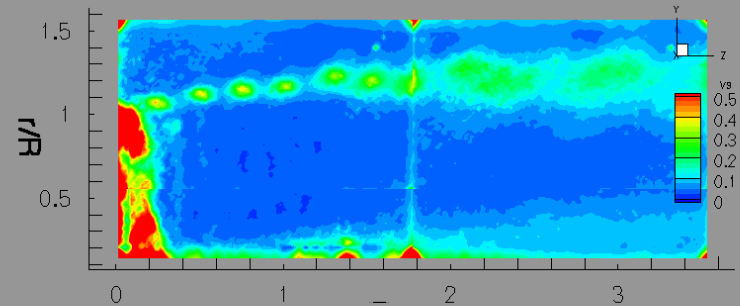
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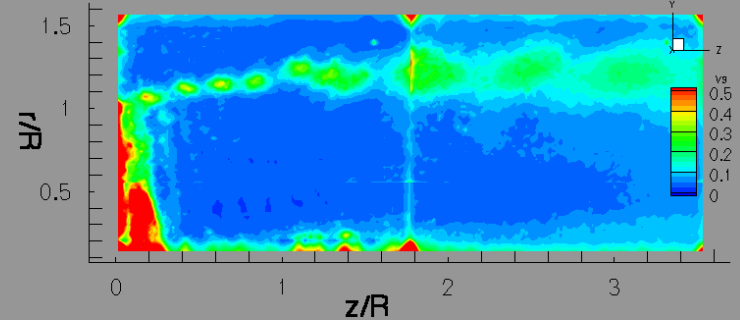
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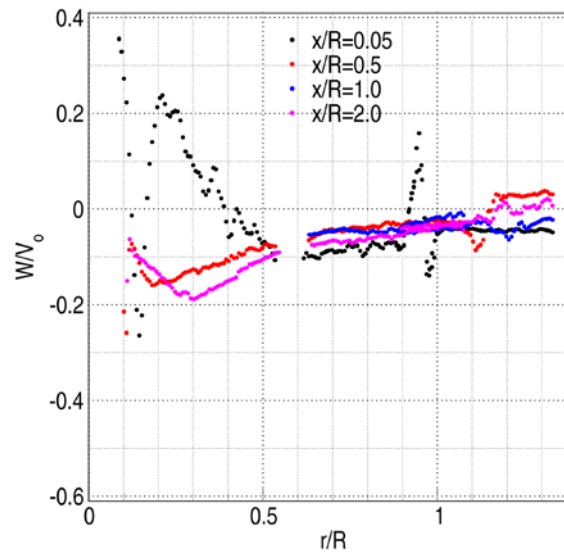
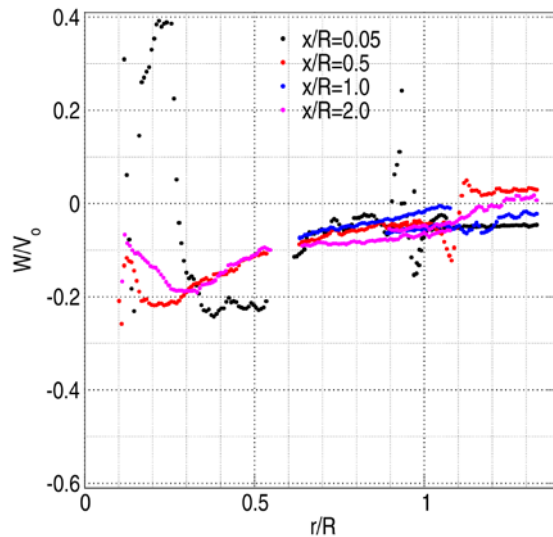
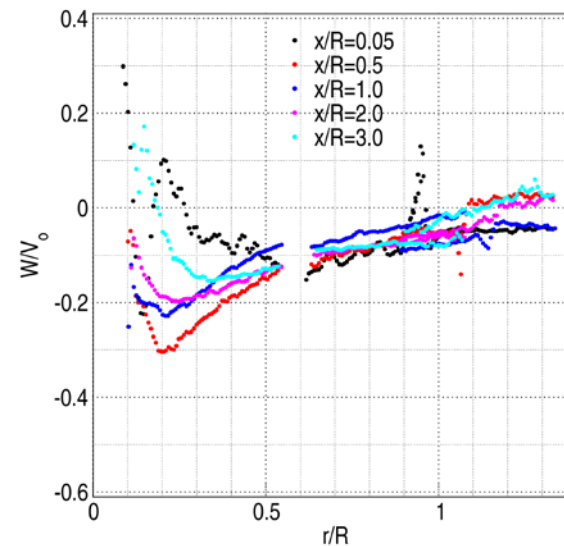
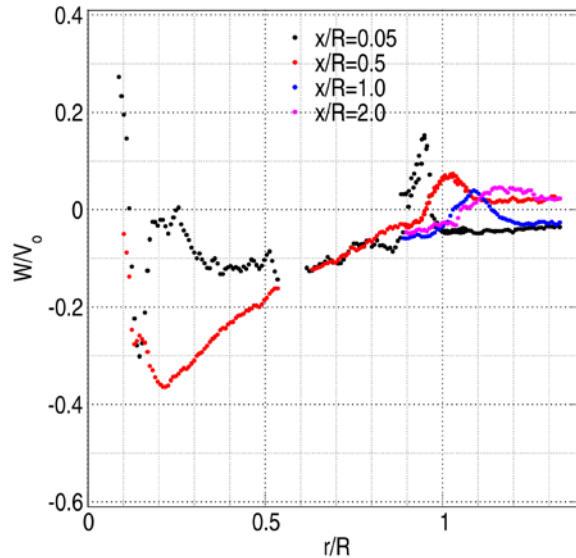
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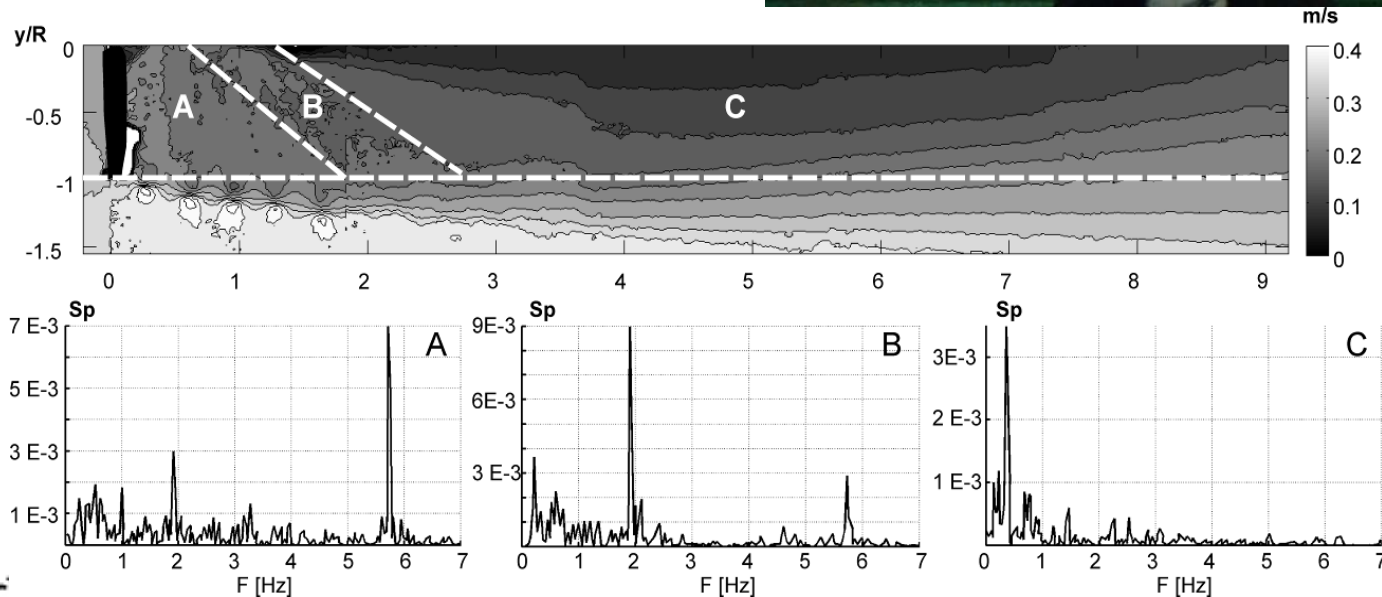
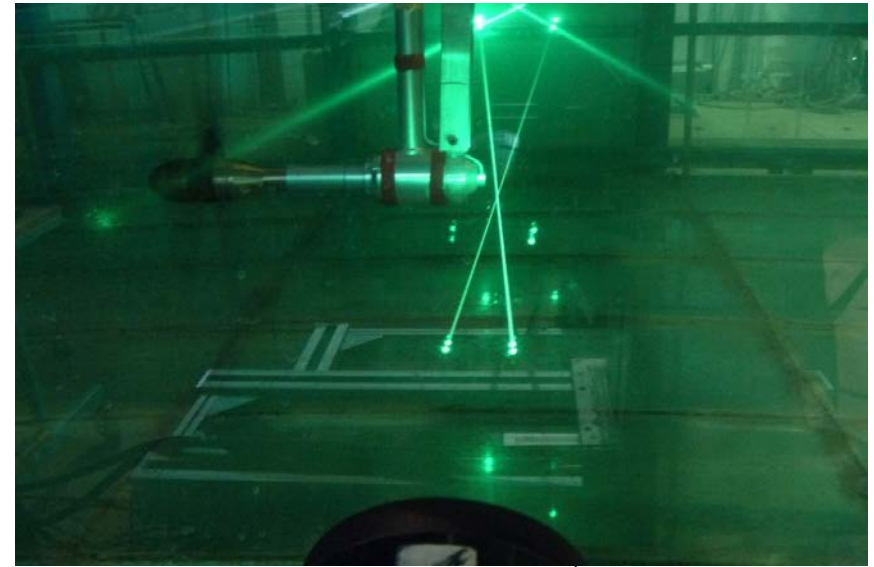
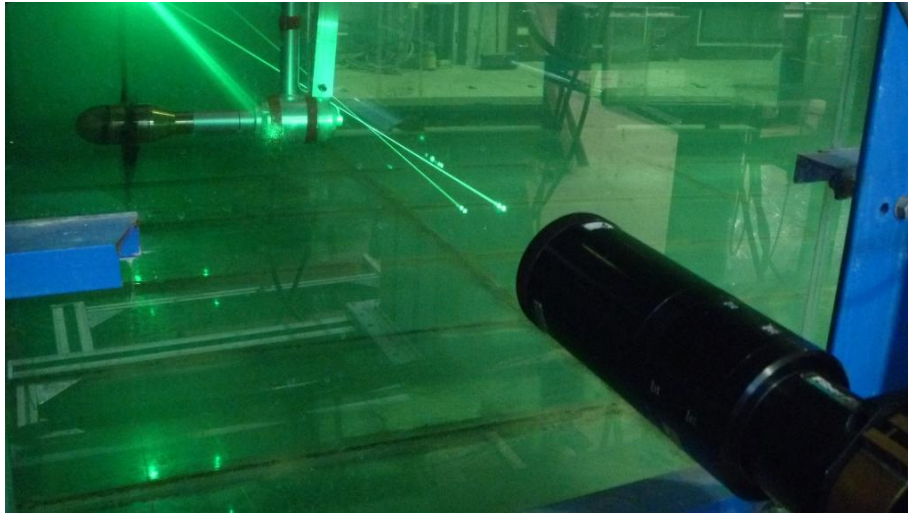
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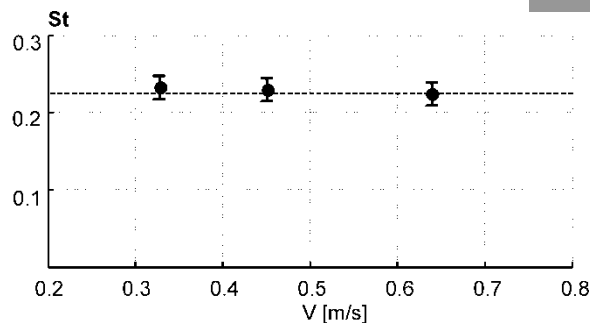
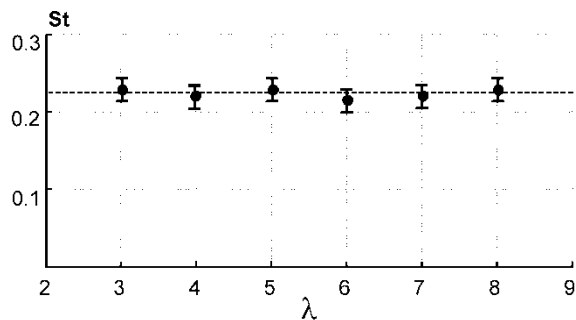
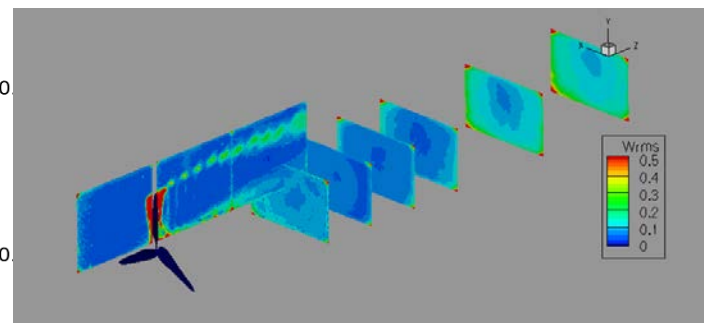
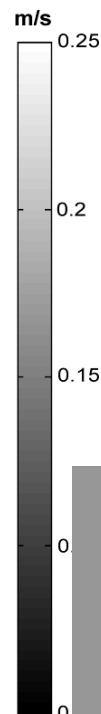
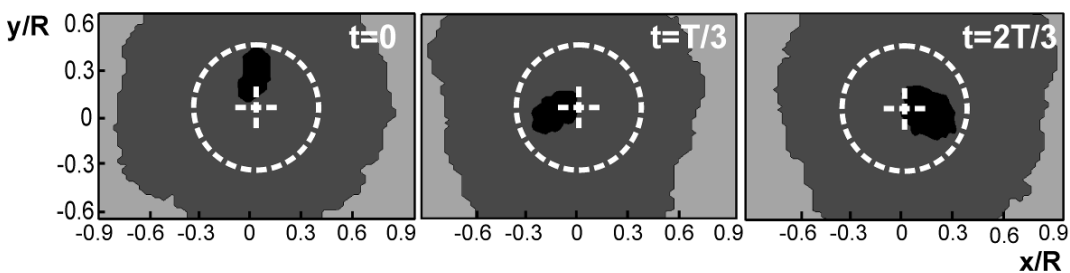
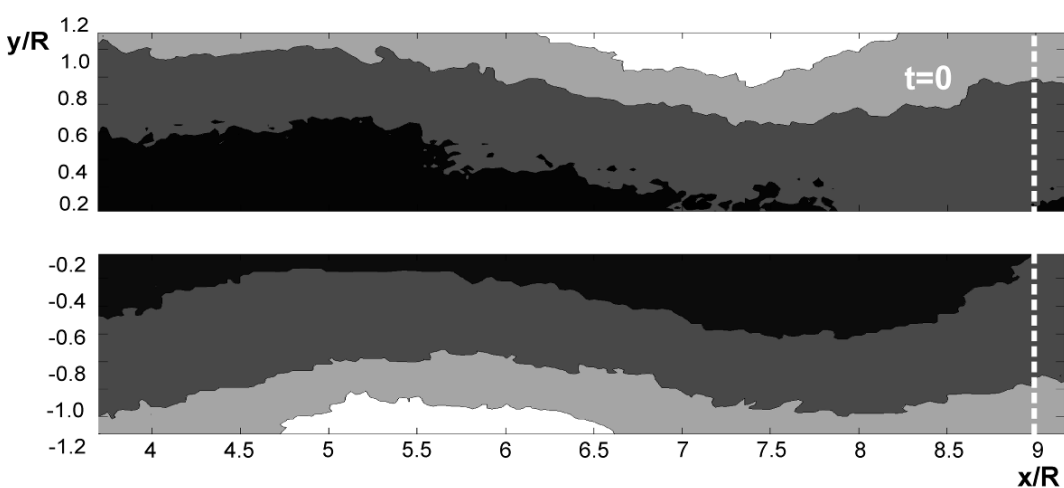
# Tangential Vel, W-mean TSR 4-7



# LDA prediction of wake frequencies



# LDA prediction of wake frequencies





# Summary

**Experimental investigation of the rotor by Glauert Opt. of  $TSR = 5$  was made at  $TSR$  3-8 :**

- **Power and trust coefficients**
- **Circulation along blade**
- **Visualization captures dynamics of helical structures**
- **PIV-mapping of the flow in the wake**
- **LDA measurements - frequencies**

## Conclusions

- **The wake pitch keeps a constant in axial direction**
- **The wake expansion coincide with the prediction of the actuator disk theory**
- **The far wake with double of the axial factor may be indicated before the wake breakdown**
- **Characteristic frequencies in the wake: blade, rotor and Strouhal**
- **The wake breakdown with a reduction of the axial factor displays under small  $Re = 20000$  too**